

FEB 09 1987

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--86-3861

DE87 005131

TITLE OPERATION OF A MAGNETICALLY FILTERED MULTICUSP VOLUME SOURCE

AUTHOR(S) R. R. Stevens, Jr., R. L. York, K. N. Keung and K. W. Ehlers

SUBMITTED TO Fourth International Symposium on the Production and Neutralization of Negative Ions and Beams, Upton, New York

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article the publisher recognizes that the U S Government retains a nonexclusive royalty-free license to publish or reproduce the published form of this contribution or to allow others to do so for U S Government purposes

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U S Department of Energy

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

OPERATION OF A MAGNETICALLY FILTERED MULTICUSP VOLUME SOURCE*

Ralph R. Stevens, Jr., R. L. York
Los Alamos National Laboratory, Los Alamos, NM 87544

and

K. N. Leung, and K. W. Ehlers
Lawrence Berkeley Laboratory, University of California
Berkeley, California 94720

ABSTRACT

The results of experimental studies on an optimized version of the Lawrence Berkeley Laboratory (LBL) volume source are presented. Negative ion yields and emittance data were obtained for operation with both H^- and D^- beams. At high arc power, H^- beam currents up to 10 mA with rms normalized emittances of $0.0080 \pi \cdot \text{cm} \cdot \text{mrad}$ were obtained from a 6.3-mm-diam emission aperture. The yields of D^- beams were approximately half those of H^- beams, and the normalized emittances were 1.7 times smaller at the same current density. The results of these studies indicate that the present operation is limited by the extraction system rather than the ion source.

INTRODUCTION

For the past year there has been an ongoing program at the Los Alamos National Laboratory to test a magnetically filtered multicusp volume source for production of H^- and D^- beams at high duty factor for accelerator applications. An optimized version of the LBL volume source has been operated in pulsed mode up to 5% duty factor at high arc power to determine the ion beam yields and emittances that can be produced. This source has been operated on both a 100-keV test stand at LAMPF and a 30-keV test stand on the ion source test stand (ISTS) facility. The results of these tests indicate that both H^- and D^- beams can be produced with sufficiently high brightness to be of use for high duty factor accelerator operation.

*Work performed under the auspices of the U.S. Dept. of Energy and supported by the U.S. Army Strategic Defense Command.

EXPERIMENTAL APPARATUS

The optimized LBL volume source¹ is shown in Fig. 1. The source chamber is 20 cm in diameter and 22 cm long. It is divided into a driver region and an extraction region by a set of filter rods containing samarium-cobalt magnets; the filter strength is 256 G-cm. The filter rods in this optimized source are located almost at the extractor plane. The source chamber is made of oxygen-free copper and is surrounded by ten columns of samarium-cobalt magnets. These columns are connected by four additional columns of magnets on the end plate to form (together with the filter rods) a full-line cusp configuration for magnetic confinement of the plasma. The primary electrons in the driver region were produced by three 0.15-cm-diam

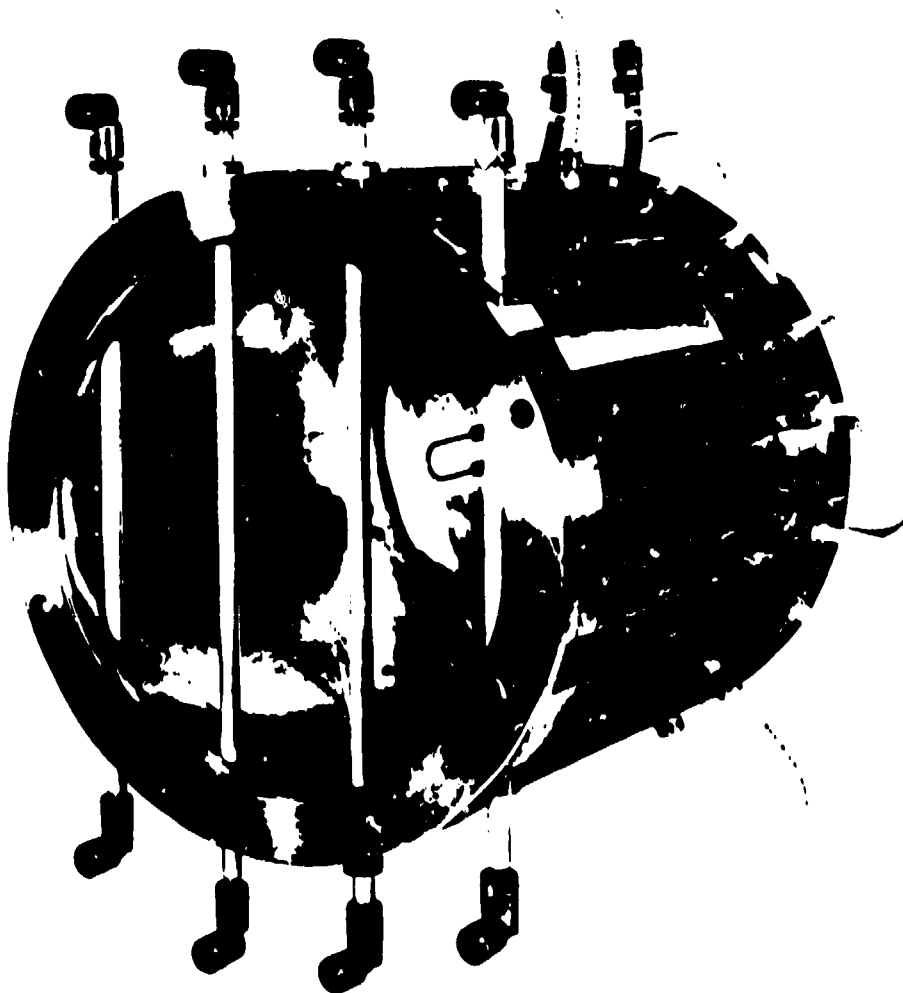


Fig. 1. The LBL magnetically filtered multicusp volume source.

tungsten filaments. The gas pressure in the source was varied from 2 to 20 mtorr, whereas the pressure in the experimental chamber varied from 2×10^{-6} to 2×10^{-5} torr.

Beam tests were carried out both on the LAMPF test stand and on the ISTS facility. The tests at LAMPF employed a tetrode extraction system similar to that used on earlier tests with the original LBL volume source.² The beams were accelerated to 72 keV, focused with a solenoid lens, mass analyzed with a 45° bending magnet, and then transported to an emittance scanner. This scanner is a conventional slit and collector system and has a spatial resolution of 0.2 mm and angular resolution of 1.5 mrad. Beam currents were measured using both toroids and Faraday cups on both the analyzed and the unanalyzed sections of the transport line. A more detailed description of this test stand is presented in Ref. 2.

The tests carried out on the ISTS facility employed a high perveance, accel-decel extraction system designed for accelerating beam currents up to 140 mA at 29 keV. A schematic diagram showing the volume source mounted on ISTS is shown in Fig. 2. Electron loading precluded operation at H⁻ beam currents over 10 mA; therefore, smaller emission apertures were installed in the plasma electrode for the present tests. A pair of samarium-cobalt magnets was also installed in the plasma electrode to reduce electron drain current. Operation of the system was then possible with a 6.3-mm-diam emission aperture. The tests on ISTS were carried out at a relatively low voltage (10 to 20 keV) but with electron drain currents up to 0.5 A. The

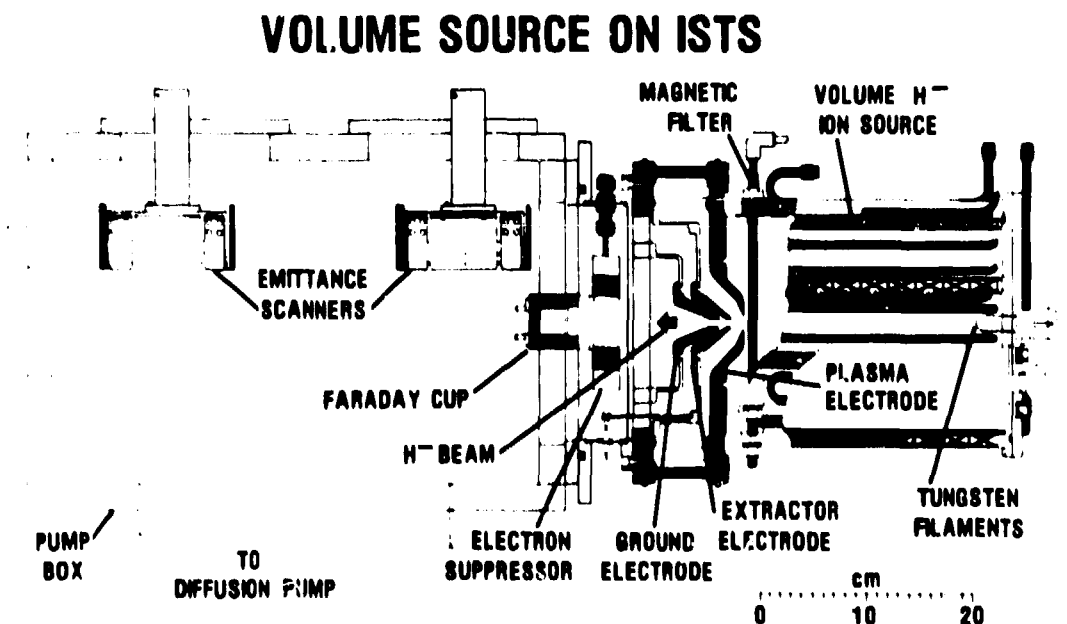


Fig. 2. The LBL volume source on the ISTS facility.

beam was extracted and subsequently transported through a double dipole magnet system having sufficient $\int B dl$ (800 G-cm) to deflect the extracted electrons onto a cooled beam stop while introducing only a 1.0-mm offset in the central trajectory of the negative ion beam at 20-keV beam energy. The negative ion beam currents were then measured using a magnetically suppressed Faraday cup. An electrostatic sweep emittance scanner was employed on the ISTS facility and was typically operated with a spatial resolution of 0.6 mm and an angular resolution of 0.5 mrad.³

In both the LAMPF and ISTS tests, the source was operated at high arc power; arc voltages up to 400 V and arc currents as high as 500 A were employed. The beam pulse lengths were typically 800 μ s, and the pulse repetition rates varied from 0.5 Hz (ISTS) to 60 Hz (LAMPF). Moreover, in both cases, the electron loading on the high-voltage power supply rather than the ion source limited operation at still higher arc power.

EXPERIMENTAL RESULTS

The negative ion currents obtained from a volume source depended primarily on the source pressure and the arc current. For a given gas pressure, the negative ion yield increases with increasing arc current to a broad maximum value and then decreases slowly. For sufficiently high arc current, the negative ion yield increases linearly with increasing source pressure and again exhibits a broad maximum before decreasing at high gas pressures. The variation of H^- and D^- beam currents obtained for several values of gas flow are shown in Figs. 3 and 4. The H^- yields obtained here are in agreement with results obtained at TRIUMF with a similar source.⁴ There is also some dependence of negative ion yield on the discharge voltage. The variation of H^- yield with arc current for several values of discharge voltage is shown in Fig. 5. For a given gas pressure and arc current, the H^- yield increases slowly with discharge voltage to a maximum value. At higher gas pressures, higher discharge voltages result in still greater negative ion yields. The corresponding yields of extracted electron current for these two cases are presented in Figs. 6 and 7. The electron currents initially increase slowly with arc current and exhibit a sharp break at a critical arc current. The value of this critical current increases with increasing gas pressure, whereas the electron drain current decreases. The electron currents in the deuterium discharge are typically 50% higher than those in a hydrogen discharge.

Emittance measurements were carried out on both test stands. Both rms emittances and the emittance distributions were measured. The results on the two test stands were similar, although somewhat lower normalized emittances were obtained on the high-voltage test stand than on the low-voltage test stand. Typical data showing the dependence of H^- and D^- normalized emittances as a function of beam current density are presented

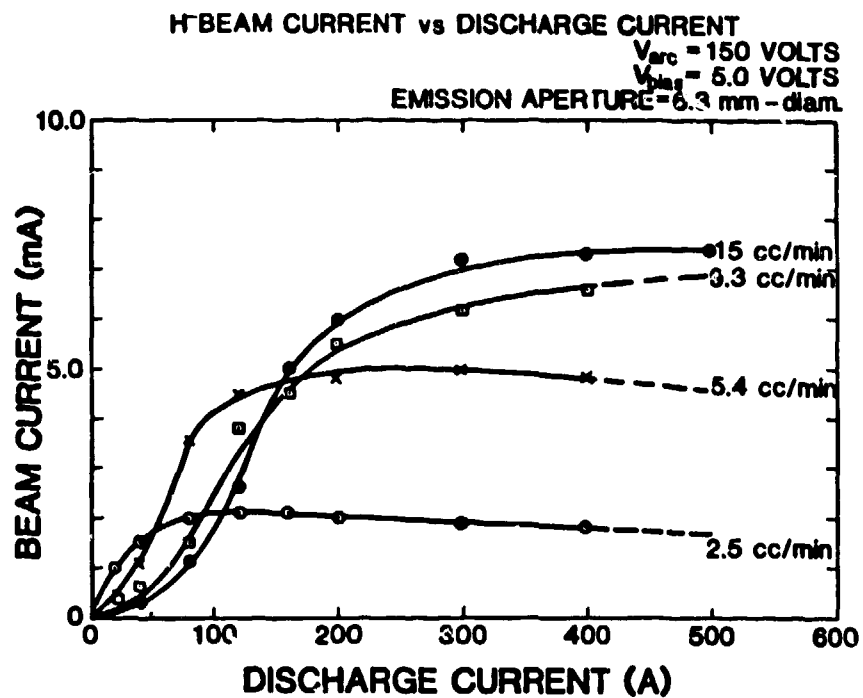


Fig. 3. H⁻ beam current vs discharge current.

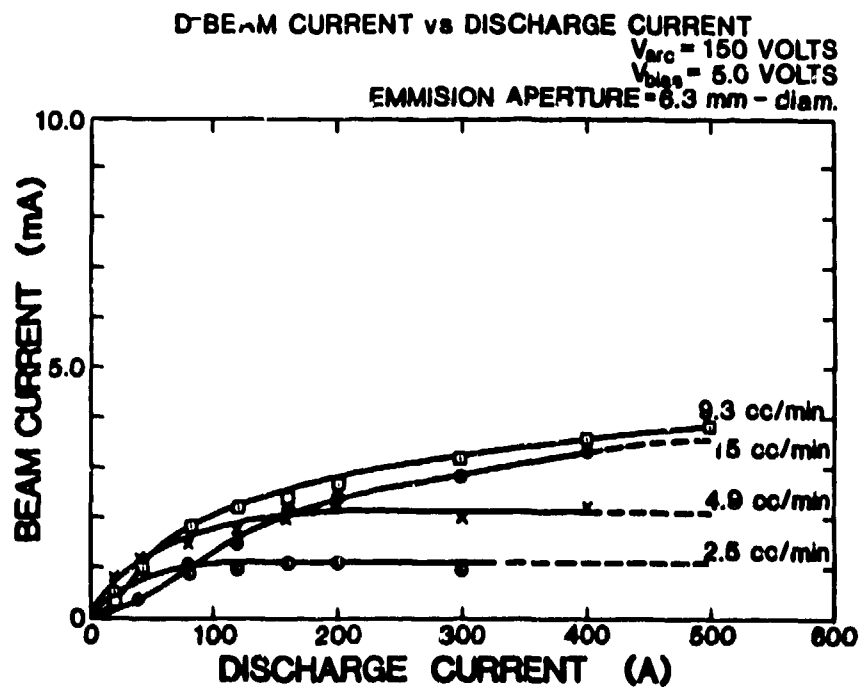


Fig. 4. D⁻ beam current vs discharge current.

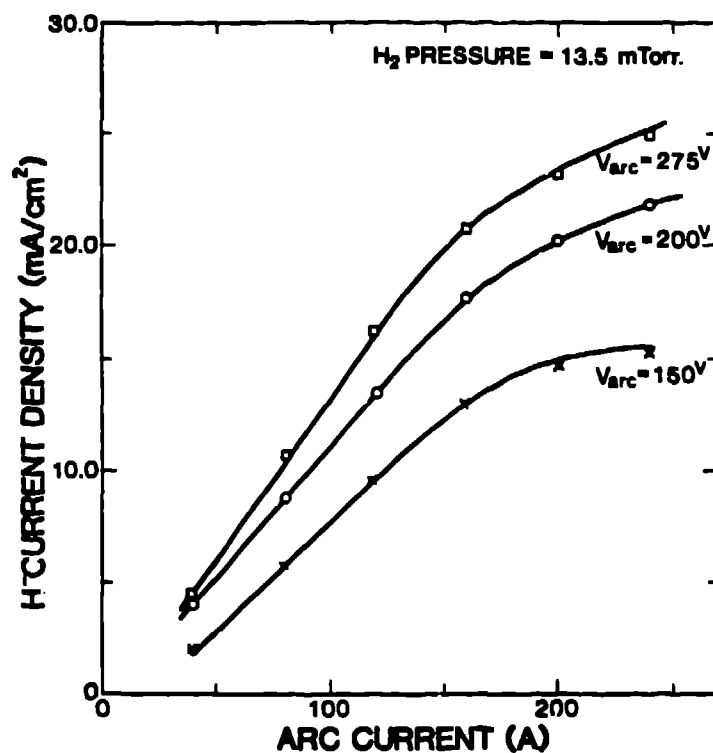


Fig. 5. Dependence of H⁻ current density vs arc current on arc voltage.

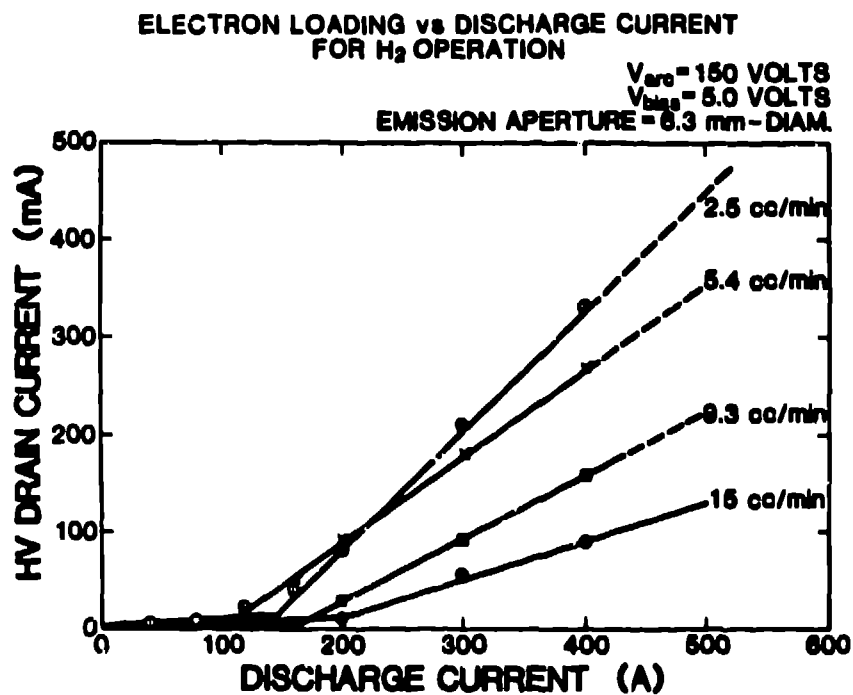


Fig. 6. Electron drain current vs discharge current for a hydrogen operation.

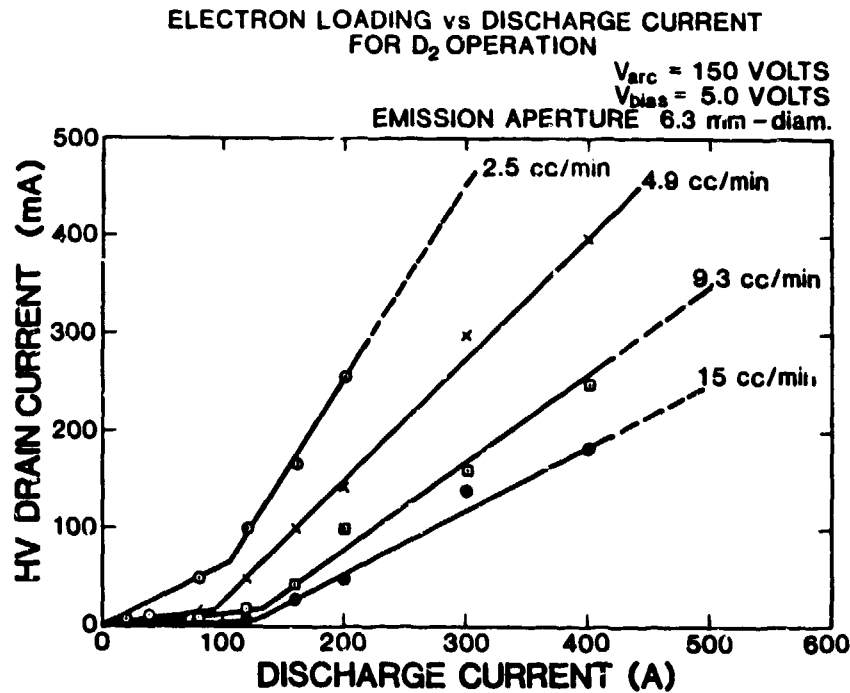


Fig. 7. Electron drain current vs discharge current for a deuterium operation.

in Fig. 8. The data for D⁻ beams were limited to half the current density as that for H⁻ beams because of the lower yields obtained for deuterium operation in this source.

In considering the emittance distribution of a beam, it is useful to plot the marginal emittance $E(F)$ for a given beam fraction F as a function of $\ln[1/(1-F)]$. A beam having a Gaussian distribution function in transverse phase space will have a linear graph in this plot; departures from Gaussian behavior, if any, are then readily apparent. To determine the rms emittance for the total beam, we have used an estimator based on the rms emittance of the marginal distribution $E_{rms}(F)$, i.e., on the rms emittance of that fraction F of the total beam above a specified threshold. For a Gaussian distribution characterized by ϵ_{rms} , we have⁵

$$E_{rms}(F) = \epsilon_{rms} (1 + (1-F) \ln[(1-F)/F])$$

For arbitrary beam distribution, this equation defines the rms emittance of an equivalent Gaussian distribution

$$\epsilon_{rms} = E_{rms}(F) / (1 + (1-F) \ln[(1-F)/F])$$

Now, by extrapolating the value of ϵ_{rms} as we let $F \rightarrow 1$, we estimate the rms for the total beam from the marginal distribution without having to obtain

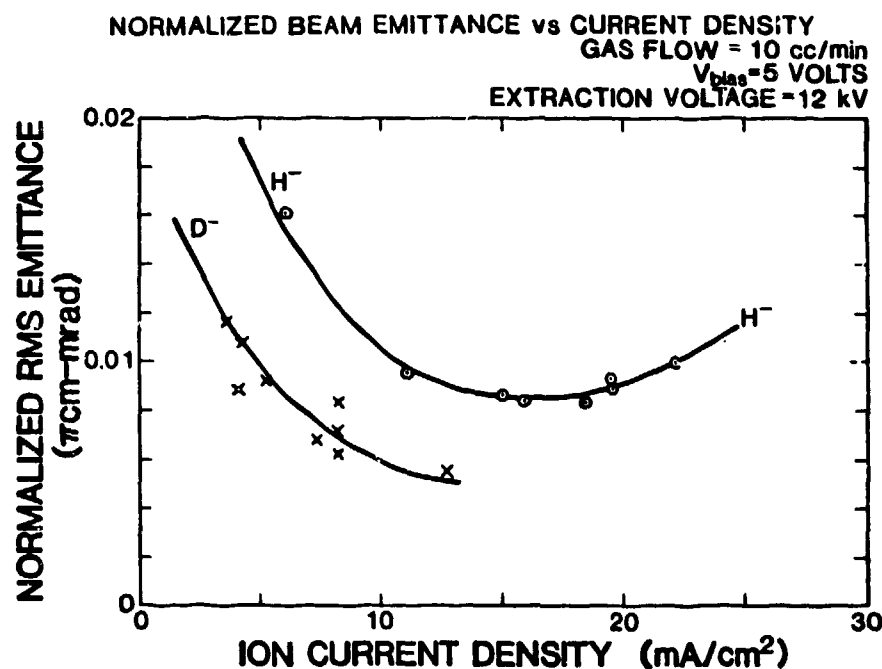


Fig. 8. Normalized rms emittance vs current density.

$E(F)$ at $F = 1$. If, in fact, the beam distribution is Gaussian, the values obtained from this estimator will be independent of F . The variation of the estimator values with F is a measure of the departure of the beam distribution from a Gaussian distribution. This procedure has been used to determine the rms emittances given in this paper.

The emittance distribution of the beams obtained from this volume source in general could not be characterized by a single Gaussian function. The plots of $E(F)$ vs $\ln[(1-F)/F]$ usually have two distinct linear regions, one for small values of F and the other for F values close to 1. In Fig. 9, a plot of $E(F)$ vs $\ln[(1-F)/F]$ is presented for several beams obtained when the ion source parameters and the total beam energy were kept constant and the extraction voltage was varied. As the extraction voltage was increased, the emittance corresponding to larger F values increased, whereas the emittance values for the smaller values of F were essentially independent of extraction voltage. The higher emittance values produced with increasing extractor voltage are associated with filamentation in the emittance distribution and, thus, the rms emittance of the total beam increases. The emittance values for lower values of F (the core of the beam) are unchanged and presumably reflect the contribution from the thermal energy spread in the ion source. Similar behavior has been observed in these distribution functions for variations in the plasma bias voltage.

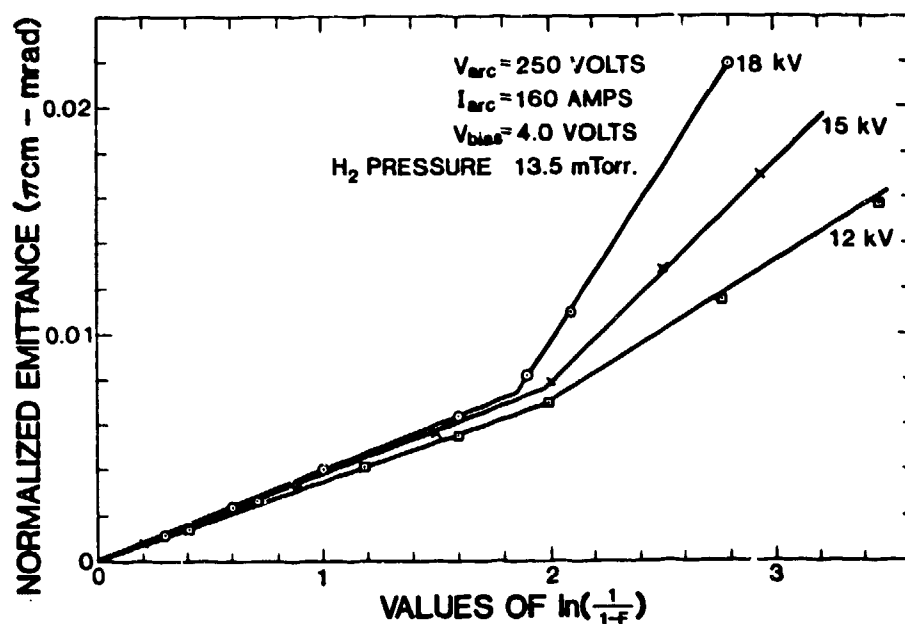


Fig. 9. Dependence of beam emittance vs $\ln[1/(1-F)]$ on extraction voltage.

However, studies carried out on the effect of the decel gap voltage in the accel-decel accelerator showed a different effect on the emittance distributions. The results obtained for a 6.0-mA H^- beam are shown in Fig. 10. As the decel voltage was increased from zero to several tens of volts, the entire emittance distribution curve was reduced. When the decel voltage exceeded 100 V, there was no further effect on the emittance distribution. This behavior suggests that the electrostatic well produced by the decel gap is reducing the emittance growth in the beam in the transport line, presumably by changing the neutralization of the beam. Similar behavior has been seen with a surface converter source⁶ and with the TRIUMF volume source.⁷

DISCUSSION

In general, operation with hydrogen and with deuterium is similar; the D^- ion currents and emittances are less, whereas the electron loading is higher. The negative ion yield curves (Figs. 3 and 4) increase approximately quadratically at low arc currents and then saturate. The quadratic behavior is consistent with the two-stage mechanism generally believed to account for the negative ion production in volume sources, i.e., formation of vibrationally excited molecules from excitation by fast electrons in the driver region followed by disassociative attachment with thermal electrons in the extraction region. For sufficiently high arc currents, the negative-ion yield saturates and depends directly on source pressure because the principal

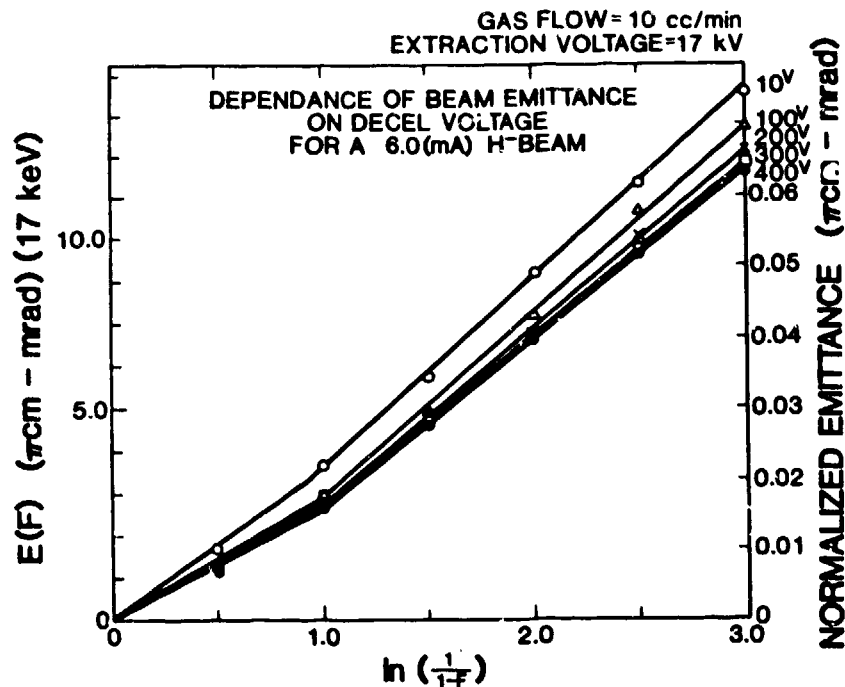


Fig. 10. Dependence of beam emittance vs $\ln[1/(1-F)]$ on decel voltage.

production mechanism (electronic excitation) and the principal destruction mechanism (collisional detachment) of the vibrationally excited molecules depend on the same fast electron density.

For very high arc currents, the negative ion yields begin to decrease because of the increasing importance of other destruction mechanisms (mutual destruction with positive ions and associative detachment with hydrogen atoms). For sufficiently high gas pressure, the negative ion yield again saturates. Estimates of stripping loss in the system are not large enough to account for this decrease, and this behavior is most likely due to a decrease in the population of the relevant excited states caused by collisions with gas molecules.

The current densities obtained in the present study (30 mA/cm^2) with a 6.3-mm-diam aperture are somewhat less than what was obtained previously² with a smaller emission aperture. The present operation, however, entailed tens of milliamperes of beam impingement on the extractor electrode, which was several times the transmitted current. The high beam loss suggests that the yield reduction is probably due to negative ion loss on the extractor electrode because of ion optical effects rather than a failure of ion source scaling with emission aperture area. Further tests are needed to resolve this question.

The emittance values obtained in this present work also do not scale exactly as expected from the previous work. The rms emittance values obtained for H^- beams with a 6.3-mm-diam emission aperture had a minimum value of $0.0080 \pi \cdot \text{cm} \cdot \text{mrad}$, whereas previously emittance values of $0.0032 \pi \cdot \text{cm} \cdot \text{mrad}$ were obtained with a 3-mm-diam aperture, which would imply $0.0067 \pi \cdot \text{cm} \cdot \text{mrad}$ with a 6.3-mm aperture. The strong dependence of emittance on beam perveance (Fig. 8) and on extraction voltage (Fig. 9) in the present study indicates that the apparent emittance growth is also due to extraction optics. In the previous studies these difficulties were in large part obviated by the use of the tetrode accelerating column, which permitted independent control of the extraction voltage and the beam energy.

CONCLUSIONS

The tests on the optimized LBL volume source have demonstrated that H^- current densities of 30 mA/cm^2 can be obtained from a 6.3-mm-diam emission aperture with normalized rms emittances of $0.0080 \pi \cdot \text{cm} \cdot \text{mrad}$. The yield of D^- ions are one-half those of H^- ions for the same ion source condition while the D^- emittances are 1.7 times smaller for the same ion current density. The scaling of beam current and emittance with emission aperture shows some apparent deterioration at this larger (6.3-mm) emission aperture diameter. Higher quality extraction systems are now needed to verify whether this scaling failure is a property of the ion source or of the extraction system now being used.

ACKNOWLEDGMENTS

We would like to thank P. Schaftstall and T. Dorr for technical assistance. This work was performed under the auspices of the Department of Energy and supported by the U.S. Army Strategic Defense Command.

REFERENCES

1. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Rev. Sci. Instrum. **56**, 364 (1985).
2. R. L. York, R. R. Stevens, Jr., K. N. Leung, and K. W. Ehlers, Rev. Sci. Instrum. **55**, 681 (1984).
3. P. W. Allison, J. D. Sherman, and D. B. Holtkamp, IEEE Trans. on Nucl. Sci., **30** (4), 2204 (1986).
4. K. R. Kendall, M. McDonald, D. R. Mosserop, P. W. Schmor, and D. Yuan, Rev. Sci. Instrum. **57**, 1277 (1986).
5. P. W. Allison, "Some Comments on Emittance of H^- Ion Beams," these proceedings.
6. J. Kwan, Lawrence Berkeley Laboratory, private communication, 1986.
7. P. W. Schmor, TRIUMF Laboratory, private communication, 1986.